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L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

AFCRL Space Science Research During 1971

(Annual AFCRL Report to the Space Science Board of the National Academy of Sciences for Submission to COSPAR)

Edited and Compiled by
A. McINTYRE
C.D. HOWARD

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13. ABSTRACT

A summary of the space science activities of the Air Force Cambridge Research Laboratories (AFCRL) in 1971, including rockets, satellites, and balloons launched, results of experiments associated with the measurement and study of energetic particles and magnetic fields, upper atmosphere physics, ionospheric physics, geodesy, and optical physics, and experiments planned for 1972, are included. The definition of space science for the purpose of this report is limited to in-situ observations and measurements using the broad definition of space.

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AFCRL Space Science Research During 1971
(Annual AFCRL Report to the Space Science Board of the National Academy of Sciences for Submission to COSPAR)

1. INTRODUCTION

This report was prepared for submission to the Space Science Board of the National Academy of Sciences/National Research Council for use in preparing the United States Space Science Program, Report to COSPAR, for the Fifteenth Annual Meeting, and is limited to ARCRL space science research results that are the product of in situ measurements obtained primarily through the use of either satellites or space probes. For the purpose of continuity, research results not previously reported to the Space Science Board are included.

More detailed accounts of the space science research results reported herein can be found in the various professional journals and in AFCRL's scientific publications.

2. AFCRL SPACE SCIENCE RESULTS—1971

2.1 Particles and Fields

2.1.1 PARTICLES

2.1.1.1 Satellite Studies

OV5-6 (1969-46B) data from outside of the magnetosphere for the solar storm of 8 March 1970 were analyzed by Yates, Katz, and Kelley of AFCRL and by Sellers

(Received for publication 12 January 1972)

and Hanser of Panametrics for proton (1-100 MeV), alpha particle (10-100 MeV), and bremsstrahlung (X- or gamma-ray, >20 keV) fluxes. Both energy spectra and time histories of these fluxes were obtained. Similar data from OV5-6 for the 2 November 1969 event were compared with the data of Blake et al from OV1-19 (1969-25C), which was in a low polar orbit.

The exposure of nuclear emulsions on recoverable Air Force satellites was continued through 1971 by Filz of AFCRL, completing a full 11-year solar cycle. Measurements of the energy spectrum of high-energy protons were made at various times in the solar cycle. Utilizing the time variation of the atmospheric density and a solution of the proton-tranport equation, the trapped-proton-loss mechanism was defined as due to energy loss by ionization in the atmosphere.

2.1.1.2 Balloon Studies

Balloon flight H71-23 was launched from Holloman AFB, N.M., by AFCRL at 0136 (UT) on 11 May 1971. It lifted 30 square meters of plastic and nuclear emulsions as well as some Cerenkov-sensitive material to 120,000 ft. The flight was successful. The results are being analyzed by Filz of AFCRL, Enge of Kiel University, Germany, and Pinsky of NASA Manned Space Flight Center. About 170 nuclei with a charge greater than that of iron were identified. The altitude at which these were recorded will be determined from the sliding plate mechanism.

The charge composition of incident nuclei in the element range from neon to nickel was determined by Fukui of AFCRL and Enge of Kiel for plastic materials flown piggy-back on other balloon's at Ft. Churchill in 1968. Meanwhile, analysis of the materials flown on balloons from Ft. Churchill in 1970 indicated needed improvements in the detectors. Improved detectors were flown piggy-back at Ft. Churchill in 1971.

2.1.1.3 Related Studies

McNulty (now of Clarkson College) studied the problem of the light flashes observed by astronauts on Apollo 11, 12, 13, and 14, and developed a theory that these flashes were caused by Cerenkov radiation by heavy cosmic ray nuclei in the interior of the eye. He then confirmed this by experiment both at particle accelerators and with the astronauts on Apollo 15.

Englade of AFCRL developed a realistic inclusive model for the post acceleration propagation of solar flare particles in a form suitable for numerical solution. The predictions of the model are in qualitative accord with existing experimental observations of the intensity vs time behavior of solar flare particles as a function of particle species, flare longitude, and heliocentric radius of observation. The model accounts reasonably well for observed features of the proton anisotropy vs time behavior as a function of energy and flare longitude. He also investigated the effect of solar boundary conditions on such propagation.

Theoretical research was conducted at AFCRL by Smart and Shea on the direct mode of particle access from the interplanetary medium to the orbit of a satellite. A cooperative effort with Gall of the University of Mexico produced a means to experimentally distinguish whether solar particles measured by satellites in the magnetosphere arrived at their detection point by a direct mode or by a diffusive mode of propagation. If the diffusive mode of propagation prevails, then the intensity at a pitch angle of 90^o will be independent of azimuth; however, if the particles arrived by the direct mode of propagation, also at a pitch angle of 90^o, there will be differences in intensity between particles in a vertical direction, an east direction, and a west direction due to geomagnetic cutoff effects.

2.1.2 FIELDS

2.1.2.1 Auroral Magnetic Field Experiments

Vancour of AFCRL conducted coordinated auroral magnetic field experiments at Fort Churchill, Canada, on 20 March 1971. A Nike Tomahawk (A08.019-1) and a Nike Iroquois (A07.019-2) were launched 80 sec apart (0542:41 and 0544:01 UT, respectively) during the peak activity of an auroral substorm. The two payloads reached apogees simultaneously. The X-component of the observatory ground station magnetometer recorded a magnetic bay of -900 to -1150 γ during the flights. Auroral patches covered the southern sky from an elevation angle of $\sim 60^o$ to zenith; at about 120 sec after Tomahawk launch a brilliant arc formed, recording 100 kR on the 5577 Å photometer and 400 kR on the 4278 Å photometer. At this time, very high fluxes of electrons were observed in the 20 to 50 keV range.

In order to improve the possibility of having the payloads pass through the disturbance, a mobile ground station magnetometer was set up at Belcher, 90 km south of the Churchill Observatory. When activity occurred, readings on X, Y, and Z magnetometers from both stations were programmed into a PDP-8 computer to determine the position, intensity, and motion of the electrojet. (The electrojet was assumed to be a line current, but an improved model will be used in the future.) Thus, the current was tracked and compared to the auroral motions observed.

The Tomahawk payload consisted of a rubidium total intensity magnetometer, electrostatic analyzers (1 to 20 keV electrons, 1 to 20 keV protons), a height to width electron detector (20 to 200 keV), and three aspect magnetometers. The Iroquois payload consisted of a cesium total intensity magnetometer, an electron electrostatic analyzer (1 to 20 keV), an electron scintillation detector (20 to 200 keV), a proton solid state detector (0.7 to 7.5 MeV), and an aspect magnetometer. All instruments except the ESAs functioned properly. The ESAs on the Tomahawk functioned briefly whereas the ESA on the Iroquois failed. These failures were traced to the channeltrons malfunctioning. They drew 1 to 3 times the normal power from their high-voltage supplies, which indicates malfunction, not corona. Data from these flights are being reduced.

Data reduction from an AFCRL Tomahawk (AT8.298) launched on 8 March 1970 was completed and analysis is near completion. The results will be published in the very near future. This flight was made during an intense substorm that came at the end of a magnetic storm. The payload passed through and remained above the aurora throughout flight. The electron electrostatic analyzer showed high fluxes were a maximum at 5 to 6 keV. Very good pitch angle distributions were obtained. The electron scintillation detector showed high fluxes in the 20 to 200 keV range. The cesium magnetometer indicated that the current was a sheet instead of a line current.

2.2 Upper Atmosphere

2.2.1 UPPER ATMOSPHERE DENSITY

2.2.1.1 Low Altitude Density Satellites

Two AFCRL low altitude density research satellites, Cannonball II (1971-067C) and Musketball (1971-067D), were successfully launched into near polar orbits from Vandenberg AFB, California, at 1711 PDT on 6 August 1971. Cannonball II, shown in Figure 1, is an 800-lb (363.2 Kg), 26-in.-diam (66.0 cm) sphere. The spacecraft was injected into a highly elliptical, 91.99° inclination orbit with an exceptionally low perigee of 134 km and an apogee of 1957 km. Because of its very high mass-to-area ratio, Cannonball II has an expected lifetime of 5 months. The primary instrumentation is an ultrasensitive triaxial accelerometer for determining atmospheric density from aerodynamic drag measurements. During the first 10 days of the life of the satellite, 80 profiles of the neutral atmospheric density were measured to an altitude of 250 km on either side of perigee. These measurements encompass a latitudinal arc of 68°. Since the orbit was nearly polar, all data were acquired at approximately 1600 hr local standard time. A preliminary analysis of some of the data obtained during quiet geomagnetic conditions was

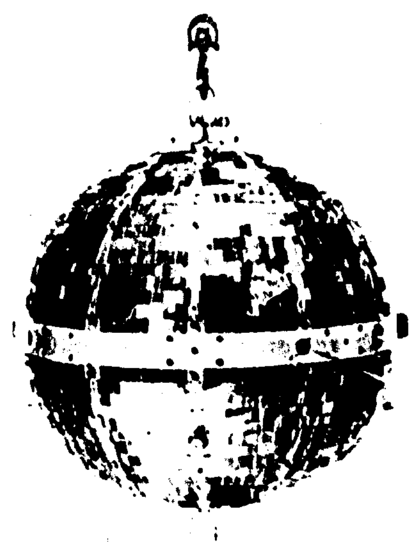

Figure 1. AFCRL Cannonball II Density Satellite (1971-067C)

made. The results indicate agreement with the Jacchia 1971 models to within approximately ± 15 percent at all altitudes. Further data reduction and analysis is being continued by Champion and Marcos of AFCRL to determine the variation in density associated with changes in geomagnetic activity and to determine the magnitude of the latitude dependence if any.

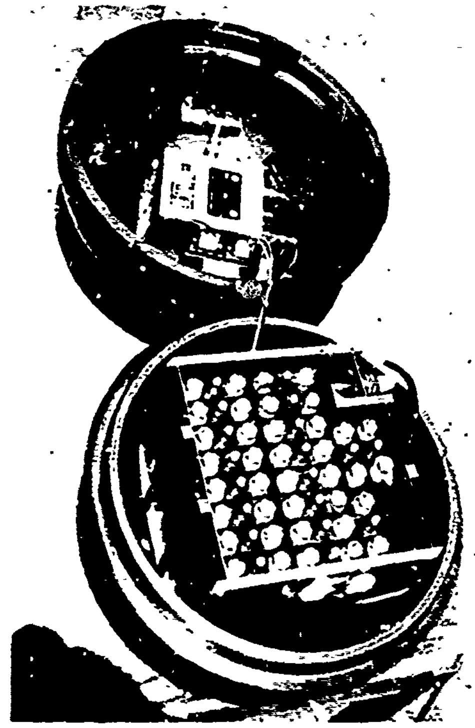

Figure 2. AFCRL Musketball Satellite (1971-067D)

The AFCRL Musketball satellite (Figure 2) was designed to provide accurate perigee density data from analysis of its orbital decay. The satellite was a 135-lb. (61.3 Kg), 12.32-in.-diam (31.29 cm) sphere containing a C-band beacon powered by non-rechargeable batteries. Initial orbital parameters were: perigee 138 km, apogee 865 km, inclination 87.61°. The lifetime of the spacecraft was 43.5 days. The beacon was automatically turned on for 4 hr every day for the first 14 days of the life of the satellite and was tracked by a network of Air Force and NASA stations. Preliminary data reduction was carried out for the first 3 weeks of the life of the satellite. These results have a resolution of 16 hr. Comparison with accelerometer data from Cannonball II indicates that the two sets of data are in good agreement. Latitudinal and longitudinal variations will be investigated.

2.2.1.3 Sounding Rocket Density Measurements

Faire of AFCRL conducted four rocketborne falling-sphere experiments to measure atmospheric density at White Sands Missile Range, New Mexico, during January and March 1971, to investigate the nature and extent of density variations associated with the winter storm season. Data obtained from two rounds launched 50 min apart on 8 January (A07.016-3 and A07.015-2) revealed density variations of 5 to 20 percent in the altitude range of 30 to 110 km. Wavelike density perturbations that attained maxima of 70 to 80 percent relative to model values were observed at altitudes of 40 km to 110 km, the largest deviations occurring near 110 km. The density values obtained by the first of two rounds launched on

12 March (A07.015-3 and A07.913-3) showed a broad, well-defined oscillating pattern that contained perturbations relative to model values ranging from 5 to 15 percent at altitudes below 80 km and deviations up to 50 percent in the vicinity of 100 km. Due to a payload malfunction, the second round only provided data below 60 km where the density variations between successive measurements were the order of 5 percent.

Faire of AFCRL completed the data reduction and analysis of the density and temperature measurements made at Eglin, Florida, during the solar eclipse of March 1970 (A07.016-1, -2). Results obtained near maximum phase showed temperatures at 56 km to be 7° to 8°K cooler than corresponding model values, while those obtained near fourth contact were approximately 10°K warmer. A pronounced temperature inversion occurred near the mesopause where the measurements at maximum phase and fourth contact were observed to be warmer than model values by 20° and 35°K, respectively. It was concluded that these effects were probably related to the solar eclipse. The results were presented at the COSPAR Eclipse Symposium at Seattle in June 1971.

An electron beam measurement of atmospheric density utilizing electron bremsstrahlung was attempted by Cohen of AFCRL from a rocket (A07.914-1) launched at 0830 UT, 27 September 1971, from White Sands Missile Range, New Mexico. An electric current of 1 mA at 4.5 keV was ejected from the rocket for 18 sec; the vehicle travelled from 120 km to 140 km during this interval. No attempt was made to directly collect the ejected electrons. A retarding potential analyzer was used to measure the energy distribution of the electrons in the return current to the payload skin. The space vehicle potential was found from this measurement to have been less than 700 V and probably as low at 400 V. Energetic beam electrons, modulated by the vehicle rotation, were detected returning to the vehicle. Signal counts from bremsstrahlung produced by the electron beam interacting with the atmosphere and rocket payload were obtained from a proportional counter on the same side as the electron beam and from a similar counter on the opposite side of the payload.

2.2.1.3 Atmospheric Models

Several studies were prepared by Sissenwine's group at AFCRL for the International Standards Organization and the U.S. Committee on Extension to the Standard Atmosphere on revisions of the existing standard atmospheres and the development of reference atmospheres. Recent meteorological rocket data were used to construct a set of atmospheric models from 20 to 90 km that represent vertical distributions of thermodynamic properties associated with extreme cold and warm stratospheric and mesospheric regimes of the bi-modal temperature distributions observed in arctic and subarctic regions during the winter.

Temperature at 45 km in the warm model is equalled or exceeded 1, 5, 20, and 30 percent of the time at Ft Greely (64°N, 146°W), Churchill (59°N, 94°W), West Geirinish (57°N, 7°W), and Heiss Island (80°N, 58°E), respectively. Rocket data obtained since 1962 show that the "U.S. Standard Atmosphere 1962" needs to be revised above 50 km if it is to be representative of nominal mid-latitude annual average conditions. A revised U.S. Standard Atmosphere for this layer is currently being prepared and will form the basis for a higher level extension being prepared at AFCRL.

2.2.2 UPPER ATMOSPHERE COMPOSITION

2.2.2.1 Atmospheric Composition at Satellite Altitudes

A new type of mass spectrometer was developed and successfully flown by AFCRL scientists (Philbrick, Narcisi, Baker, and Trzcinski) on the Air Force OV1-21 (1971-067B) satellite. The instrument, referred to as a velocity mass spectrometer (VMS), makes use of the high satellite velocity to separate the species by energy in a retarding field. Figure 3 shows the operating concept of the VMS, with a schematic representation of the instrument in the upper part of the figure and an example spectrum in the lower part. The incoming neutral gas flux has a velocity of about 8 km/sec and is ionized by the electron beam. The ions that are formed in this field-free region continue with the original velocity of the neutral atom. A retarding voltage is applied to a grid to separate the ions by energy (He, O, N_2 have energies of 1.3, 5.3, and 9.3 eV respectively). The instrument has an advantage over other types of mass spectrometers and density gauges because it is not sensitive to recombined or desorbed gas species. The orbit was circular polar near 800 km and real time data were obtained over the 4-week lifetime of the battery supply. The data are being prepared for analysis and appear to be of good quality.

Analysis of the mass spectrometer measurements of the neutral and ion composition experiments performed by Narcisi's group at AFCRL on the OV3-6 and OV1-15 satellites is nearing completion. The OV3-6 (1967-120A) measurements were obtained in a circular orbit near 400 km over a period of 15 months from December 1967 through March 1969. The OV1-15 (1968-059A) measurements were obtained over a 3-month period in 1969 and cover the altitude region between 150 and 500 km. The OV3-6 results indicate a temperature maximum near local sunset and a broad density maximum in the late afternoon. The inference of the temperature maximum, later in the day than the density maximum, results from the fact that the molecular species represent about 10 percent of the total density near local sunset and only about 1 percent or less of the total density near local noon. Atomic nitrogen was observed to be present in concentrations of about 1 percent of the atomic oxygen density at local time between noon and sunset.

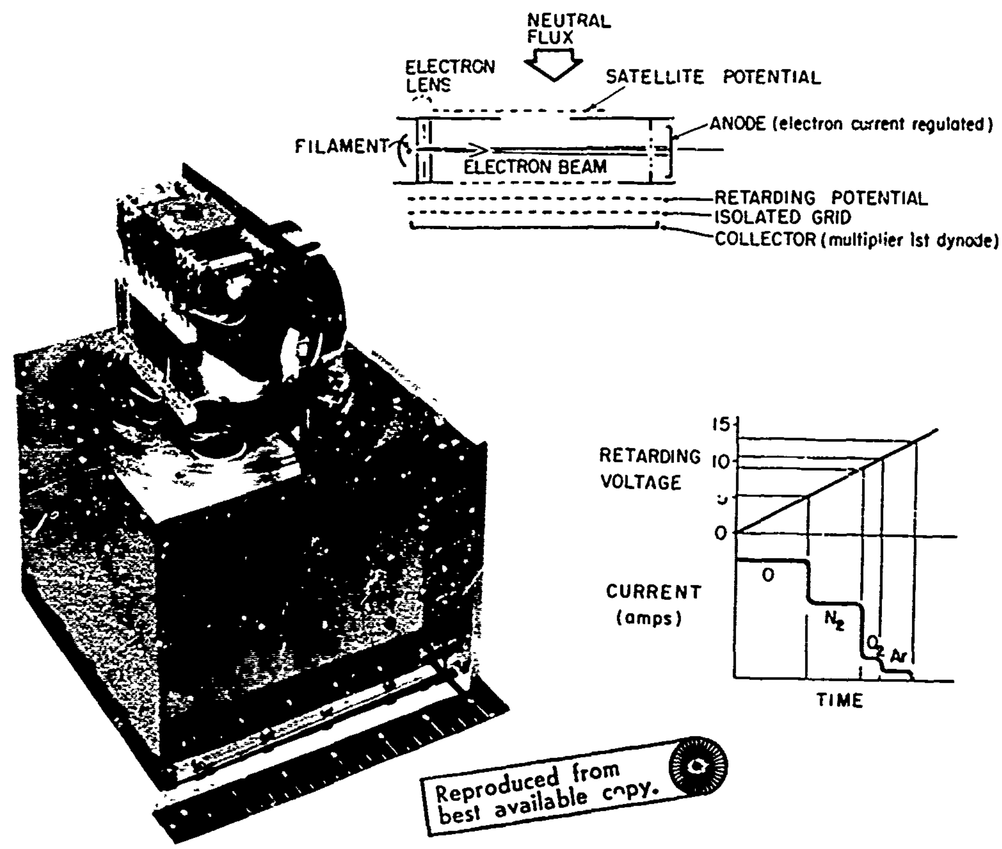

Figure 3. AFCRL Velocity Mass Spectrometer and Sample Spectrum

2.2.1.2 Sunrise D-region Composition

Four Nike-Iroquois rockets with ion mass spectrometers and Langmuir probes were launched around sunrise from Wallops Island on 6 October 1971 in a program conducted by Narcisi and his colleagues at AFCRL. The objectives of the program were to determine D-region electron detachment processes from negative ion composition measurements and D-region ionization sources at sunrise through positive ion composition measurements. A cryopumped positive ion mass spectrometer (A07.902-6) and negative ion mass spectrometer (A07.101-3) were launched when the entire D-region was in darkness. Following these, a negative ion mass spectrometer (A07.101-4) was fired at a solar zenith angle of 94°, so that 4 eV radiation penetrated below 80 km, and a positive ion mass spectrometer (A07.101-2) was launched at a solar zenith angle of 90°. Excellent data were obtained from all instruments, except the last positive ion spectrometer that failed during excessively 'hard' Iroquois burn. From a cursory examination of the flight data, which are in the early reduction stage, the following observations were evident: very large negative ion clusters, up to 200 amu, were measured below 90 km; mass 46^- amu, probably NO_2^-, was measured before sunrise but was absent after sunrise; relatively large quantities of chlorine ions, 35^- and 37^-, were seen in the D-region; large positive ion clusters up to 93 ± 1 amu, the upper limit of the mass scan, were present below 90 km, including mass numbers that could be identified as the $H^+(H_2O)_4$ and $H^+(H_2O)_5$ water clusters; and a sporadic-E layer comprised of meteoric ions was present in the lower E region and evident in ionograms taken during flight.

2.2.2.3 Composition Measurements During Solar Eclipse

Positive ion composition measurements conducted by Narcisi of AFCRL in the lower ionosphere during the November 1966 solar eclipse and negative ion composition measurements made during the March 1970 solar eclipse were analyzed. The D-region results provided strong evidence for the existence of a fast ionospheric reaction that converts NO^+ to water cluster ions, but the actual reaction could not be determined from the measurements. (In the highly disturbed D-region, the lifetime of NO^+ is apparently too small for this process to be significant.) The E-region results exhibited the expected behavior of the molecular ions during the eclipse; both the NO^+ and O_2^+ concentrations decayed while the NO^+/O_2^+ ratio increased with solar obscuration. The long-lived meteoric atomic ions were generally unaffected in the short period of the eclipse. A meteoric ion layer that was submerged prior to totality became prominent after the molecular ions fully decayed at totality and produced a sporadic E layer at 105 km.

Negative ion composition measurements near totality again showed the heavy negative ion clusters predominant below 92 km. Relatively large concentrations of O^-, O_2^-, NO_2^-, and NO_3^- were detected between 90 and 98 km, but they were seen only in the eclipse measurements and cannot presently be explained.

2.2.2.4 Auroral Composition Results

During the PCA 1969 rocket program, positive ion composition measurements were made in a Class II^+ aurora in the E-region. Although the ion chemistry of the quiescent E-region is fairly well understood, the auroral rocket measurements yielded anomalously large NO^+/O_2^+ ratios. Increases in nitric oxide concentrations of up to 10 times normal are required to explain these results. From the rocket measurements, an upper limit of nitric oxide concentration of 2×10^9 cm^{-3} was calculated. For apparently similar auroral conditions, Zipf, Borst, and Donahue (J. Geophys. Res. 75: 6371, 1970) reported a considerably greater nitric oxide concentration of 3.8×10^{10} cm^{-3}. Despite this discrepancy it seems clear that nitric oxide is greatly enhanced in auroras, although the processes responsible for the increase are unknown.

2.2.3 COORDINATED MEASUREMENT PROGRAMS

2.2.3.1 AFCRL GENIE Program

AFCRL, in cooperation with other agencies, conducted a major field program nicknamed Project GENIE (geophysical experiments for neutral species in the ionospheric E-region). This series of sounding-rocket flights combined chemical release and falling sphere experiments to measure wind fields and temperature, density, and atomic oxygen profiles. It was carried out at Eglin AFB, Florida, on 18 May 1971. A total of 15 rockets were flown in a 10-hr period. Data analysis is in progress for most of the experiments.

AFCRL experiments flown during this program included falling sphere density measurements by Champion and Faire, photometric oxygen profile measurements by Weeks, chemical releases—including trails and puffs—for measurement of wind fields by Rosenberg and MacLeod, turbulence spectra by Zimmerman, AlO temperatures by Kitrosser, and total density and atomic oxygen profiles by Golomb and Good. Simultaneously, inflatable-sphere experiments were conducted by Olsen of White Sands. Barnes of AFCRL measured meteor winds by ground-based radar, and ionospheric conditions were monitored with a digital ionosonde operated by Bibl of Lowell Technological Institute.

Horizontal and vertical wind motions were measured on the twilight flights (A07.917-5, .918-2 and .917-6) using lithium puffs superimposed on trails of trimethylaluminum (TMA). This observation covered the 90 to 140 km region. Smoke releases were made as a string of points in the 60 to 90 km region (A07.917-5) to obtain turbulence spectra measurements. Two new smoke generators were used: a sodium-Fe_2O_3 thermite mix, and an aerosol dispenser consisting of Al_2O_3 particles dispersed by a gas generator.

Studies of the formation of a luminous vapor puff for marking vertical motions at nighttime were continued (A07.921-1 and .918-4). Releases of gaseous TMA were made by heating liquid TMA above its boiling point. A fraction of the TMA apparently condensed, since particulate matter moved with rocket velocity and filled the space between the puffs, but the discrete puffs were clearly identifiable.

The nitric oxide release method has been used for several years to determine atomic oxygen profiles in the upper atmosphere. The NO release (A08.919-2) during the GENIE program indicated a "normal" [O] profile, with a steep rise to a peak at 100 km where $[O] \cong 7 \times 10^{11}$ cm^{-3}. At higher altitudes the number densities fall off nearly in accordance with diffusive equilibrium. Contrary to this, previous NO releases at Churchill in 1968 and Hawaii in 1969 indicated an "anomalous" profile with a trough at 110 to 120 km and a secondary broad peak in the 130 to

150 km region. It is postulated that the "anomalous" profile results from the occasional sandwich structure of the atmosphere, where two or more turbulent layers are interspersed with smooth laminar layers. The multiple turbulent structure is determined by the presence of layered wind-shear regions. Alternatively, some form of wave motion could also be a plausible explanation for the peculiar [O] profiles.

During GENIE, evening twilight releases of TMA puffs covered the 140 to 180 km region (A07.917-5). A single release of 2 kg was discharged at 135 km at dawn (A07.917-6) to obtain time variance data. From the fluorescent band shapes, the temperature of the radiating molecules and, by inference, that of the atmosphere can be determined. In the most recent release (A07.106-5), particular emphasis was placed on obtaining sufficiently intense spectra at the low altitude of 120 km. This was achieved by releasing 16 kg of TMA instantaneously by rupturing the skin of the container. The clouds were spectrally scanned for from 15 to 20 min to observe possible temporal variations of the temperature. The GENIE series also included experimental releases of Sr, Li, and Na metal vapors and liquid iron-carbonyl to evaluate techniques for the release of metal vapors and studies of oxide formation as a function of release altitude. The strontium releases (A07.917-6) produced atomic strontium neutral clouds between 90 and 145 km. At no time was the spectrum of strontium oxide observed from these releases. Li metal vapor "puff" releases were made in a continuing evaluation of techniques to provide twilight markers for vertical motions and to provide further data in a study of the condensation and oxidation of the lithium vapor as a function of altitude (A07.917-5, .918-2, and .917-6). Na "puff" releases were made to compare results with the Li "puffs" released from the same rocket (A07.918-2). Iron carbonyl was released (A07.917-4 and .918-4) both at night and at twilight. Release techniques used included the venting of the liquid as a trail, and a release initiated by a high explosive. All releases were visible either in the chemiluminous mode (night) or in the resonant fluorescence (twilight) of FeO, which is formed in the reaction of the iron carbonyl with the ambient.

Theoretical calculations were performed by Klein and Corbin of AFCRL for the scattering of H-F waves by ellipsoidal charge distributions in the presence of a magnetic field. Barium releases in the upper atmosphere take on a form that can be approximated by a prolate ellipsoid aligned along the magnetic field. They calculated the differential cross section for the previously mentioned orientation and found that the inclusion of a magnetic field decreases the differential cross section by a small amount. When these results were compared to a conducting prolate ellipsoid whose dimensions are similar to the critical ellipsoid of the charge distribution, much larger values were obtained for forward scatter, and extremely small values for the backscatter.

The visible spectrum of the vibrational bands of BaO was measured from previous releases. The band intensities were recorded and the electronic transition moments were calculated, using the Nicholls rescaling method. The vibrational populations were then deduced by Hoffman and Best of AFCRL.

A practical technique was developed by Quesada and MacLeod of AFCRL for deriving scalar diffusion coefficients and local wind shears from photographic observations of chemical tracer puffs deposited in the atmosphere. Analytic solutions were obtained showing that the puff density is a Gaussian function of space at each time for an atmosphere possessing a constant vertical shear. It was shown that the sum of the Gaussian half-widths squared projected on the film plane is a cubic polynomial in time with coefficients that depend on the geometry, shears, and the diffusion coefficient. These parameters may be determined experimentally by a least-squares fitting procedure. An important feature of the technique is that densitometric analysis is necessary only from one observation site, though at least two sites are required to determine the range and orientation.

Horizontal shears of horizontal winds were derived by MacLeod of AFCRL from two chemical trail experiments flown in 1967. The vertical profiles of the winds and the vertical shears in the 93 to 160 km altitude region exhibited the characteristic oscillatory structure with dominant wavelength increasing with altitude. The vertical profiles of the horizontal shears also exhibited an oscillatory structure, but with an apparent dominant wavelength half of that of the winds and vertical shears. The amplitudes of the horizontal shear oscillations varied among the shear components and amounted to 1 to 10 percent of the amplitude of the vertical shear oscillation. The horizontal divergence and vertical vorticity had comparable amplitudes of approximately 10^{-3} sec^{-1}.

Moses of AFCRL made theoretical studies of the motion of vapor trails in winds of constant shear in the case of potential, vorticity, and stratified flows. Wind motions were considered for a vertically stratified atmosphere on a rotating earth. Certain exact solutions of the equations of fluid motion were introduced whose parameters could be adjusted so that the fluid motion approximated the mean motion of the upper atmosphere winds observed by vapor trails. The helical motion in the hodograph space was reproduced.

2.2.3.2 Ion Mass Spectrometry of the Lower Ionosphere – A U.S./U.K. Rocket Program

A rocket program was conducted by Narcisi and colleagues at AFCRL in conjunction with the Mullard Space Science Laboratory (MSSL), England, at Eglin AFB, Florida, in May 1971. The objective of the program was to compare D-region sampling methods for water cluster ions for attached (MSSL) and detached (AFCRL) shock waves ahead of the sampling probe. In the latter case it is suspected that the weakly bound water cluster ions may be collisionally fragmented when traversing the shock heated gas. Daytime and nighttime measurements were obtained from two Nike-Iroquois payloads (A07. 902-7 and A07. 902-8) containing three instruments each: a positive or negative ion quadrupole mass spectrometer (AFCRL), a positive ion short-path-length mass spectrometer, and a plasma probe (MSSL). The mixed water clusters $NO_3^-(H_2O)_n$, along with small amounts of $CO_3^-(H_2O)_n$ (n = 0 to 5), were dominant in the nighttime negative ion data, but in the cold mesopause (80 to 90 km) the presence of appreciable quantities of negative ions exceeding 160 amu were detected. The daytime AFCRL positive ion measurements were also programmed to examine the effects of the sampling electric field. It was found that a large electric field causes extensive fragmentation of cluster ions when the instrument is sampling in the vehicle ram direction, and that this effect diminishes when the instrument is directed toward the rarefied vehicle wake. The measurements are presently undergoing analysis and will be compared with MSSL results.

2.2.3.3 Twilight Neutral Composition and Density Variations

A coordinated rocket program was conducted from Wallops Island, Va., by AFCRL in October 1971; seven rockets were launched around sunset on 5 October. The rocket payloads were designed to measure twilight variations in neutral composition and density and, especially, the changes in atomic oxygen, molecular oxygen, and ozone between 60 and 120 km. The experimental instrumentation consisted of neutral mass spectrometers (A07. 101-5 and -6), ultraviolet absorption photometers, 2 to 8 Å X-ray counters (A08. 103-2 and A07. 913-6A), and 7-in. falling spheres (A07. 102-4 and A07. 913-6) instrumented with omnidirectional accelerometers. The program was highly successful. Cryopumped quadrupole mass spectrometers were utilized to measure the neutral species between 70 and 120 km. The mass range of from 4 to 110 amu was swept in 1 sec, and all species larger than 70 amu were measured in the subsequent 0.050 sec. The electron ionizing energy was switched on alternate mass scans between 19 eV and 85 eV to obtain more definite measurements of atomic oxygen. Concentration-height profiles of O_3 and O_2 will be obtained from UV absorption measurements at 2600 Å, 2750 Å (O_3), Lyman α, and the Schumann-Runge maximum (O_2). Two rockets (A07. 913-6A and A07. 101-5) were launched almost simultaneously to allow correlation between the two techniques for measuring O_2 and O_3. No such correlations between absorption and mass spectroscopy have previously been made in the upper atmosphere. Neutral atmospheric density, temperature, and pressure will be determined from falling sphere drag acceleration results.

2.2.4 SOLAR EXTREME ULTRAVIOLET

2.2.4.1 AFCRL Solar Extreme Ultraviolet Rocket Experiments

Hinteregger's and Heroux's group at AFCRL conducted three successful experiments with rockets instrumented with grazing incidence spectrometers to measure the absolute intensities of solar extreme ultraviolet (XUV) radiation in the wavelength range of 30 to 1220 Å and the attenuation of this radiation in the earth's atmosphere. The spectrometers were equipped with either one or two concave gratings, and each spectrometer had several exit slits and detectors that simultaneously scanned different wavelength regions. The detectors were channel electron multipliers and thin-window gas-flow Geiger-Mueller counters operated as photon counters. The spectrometers were calibrated before flight with an estimated accuracy of about $\pm$25 percent over the entire wavelength range of 30 to 1220 A One experiment launched 16 March 1971 (A04.002-2) recorded, nearly continuously, the attenuation of eight selected solar emission lines as a function of altitude between about 100 and 270 km. The emission lines selected for analysis were situated in wavelengths between 284 and 1206 Å. The data obtained from this experiment are being reduced and will be used to determine the vertical distribution of the atmospheric constituents N_2, O_2, and O.

The other two rocket experiments were flown simultaneously on 9 November 1971 to obtain the absolute intensities of solar XUV between 30 and 1220 Å incident at the top of the earth's atmosphere, with improved spectral resolution and photometric accuracy. One of these rocket spectrometers (A03.002-3) recorded the solar spectrum between 220 and 1220 Å with a spectral resolution of 0.6 Å and also measured the attenuation of four selected solar lines between 304 and 1206 Å as a function of altitude. The attenuation data will be used to correct the data obtained over the complete wavelength range of 220 to 1220 Å for atmospheric absorption. The other rocket spectrometer (A03.002-4) flown on 9 November 1971 recorded solar XUV intensities in the wavelength range of 30 to 205 Å with a spectral resolution of 0.15 Å.

Because the rocket experiments of 9 November 1971 were flown simultaneously, the data obtained for the different wavelength regions covered by each spectrometer refer to identical physical conditions in the solar atmosphere. These data will be used for spectral line identifications in the solar XUV and for the determination of elemental abundances in the solar atmosphere. The data will also permit accurate determinations of the intensity ratios of XUV spectral lines from the lithium-like and beryllium-like ions present in the sun. From the intensity ratios, the electron temperatures and densities in the region of the solar atmosphere, where the emission lines of the ions are predominantly emitted, will be deduced. These experiments are a continuation of AFCRL research that was initiated after the first flight on 4 April 1969 of a newly developed spectrometer equipped with several photon detectors. The analysis of the line intensity ratios of the lithium-like ions and the identification of solar XUV lines between 50 and 300 Å, based on the rocket spectrometer flown on 4 April 1969, were completed during 1971.

2.2.5 OTHER AERONOMICAL STUDIES

2.2.5.1 Turbulence Studies

The Richardson number analysis by Zimmerman, et al, of AFCRL, of wind and temperature measurements, as determined from rocket-borne grenade experiments, shows that the atmosphere above approximately 75 km is usually turbulent in a spatially intermittent manner. The latitudinal variation of the Richardson number, for the years 1965, 1966, 1967, indicates strong turbulence present almost 100 percent of the time at high northern latitudes (60°N) and at the equator (5°S), while the midlatitude (38°N) data show turbulence at some altitudes above 75 km for approximately 50 percent of the time. The biseasonal variation (summer and winter) of the data shows the northern latitude winters as having extremely intense turbulence, with estimates of the local rate of dissipation as high as 5×10^5 ergs gm^{-1} sec^{-1}, while the summer values are not as large. Further, the data show that turbulence extends to a lower altitude in the winter (about 45 km) than in the summer. The equatorial results show more intense turbulence in the summer than the winter, with the turbulence regions extending to a lower altitude in the summer. The midlatitude data shows the lowest turbulent amplitude, with average dissipation rates of the order of 10^4 ergs gm^{-1} sec^{-1}. These midlatitude results are in accord with the results of chemical trail wind analysis by Zimmerman and Rosenberg who find the average turbulent dissipation at 95 km as due to shears greater than 30 m sec^{-1} km^{-1} and with a value of about 1×10^5 ergs gm^{-1} sec^{-1} but present only about 1/4 of the time. In summary, the earth's atmosphere has effectively two turbulent regions: one below the tropopause and terminated at the earth's surface, the other centered near the mesopause and terminated above approximately 105 km by the combination of the rapidly increasing molecular viscosity and associated smaller shears.

2.3 Ionospheric Physics

2.3.1 JOINT SATELLITE AND AIRCRAFT STUDIES OF THE AURORAL OVAL

Joint satellite and airborne measurements using a jet aircraft were conducted by Gassmann and colleagues at AFCRL. This combination of measurement techniques provided a substantial broadening of results since an aircraft, in contrast to a satellite, is not restricted in local time. The phenomenology of the auroral oval in its relation to the magnetosphere was studied. This approach used airborne and ground-based techniques for observing large-scale phenomena that occur in the arctic ionosphere. The latter plays the role of an observing screen for magnetospheric processes. The Flying Ionospheric Laboratory of AFCRL (KC-135) is equipped with ionospheric sounding equipment, photometers, spectrographs and all-sky cameras. One goal of the measurements was to position the aircraft at subpoints of the satellites ISIS-I and/or II at selected locations and times. A circum-oval flight allowed a first mapping of the local time extent of the region in which the solar wind interacts directly with the ionosphere; it is identical in location with the dayside auroral oval.

The origin of the precipitating particles in this region was identified by Heikkila as being the thermalized solar wind plasma gaining entrance through the magnetospheric cusp. The solar wind location is inferred by Buchau, et al, of AFCRL by the photometric detection of enhanced (subvisual) emission at 6300 Å, and by radio soundings that detect F-layer irregularities within the same band. The auroral oval is located simultaneously by all-sky camera photographs. This band lies between 75 and 80 deg corrected geomagnetic latitude, is 2 to 5 deg wide and extends from 0700 through noon at least to 1700 corrected geomagnetic time.

Latitudinal cross sections of the bottomside polar F-layer were constructed from ionograms recorded in the aircraft. Analysis of the cross sections shows that an F-layer irregularity zone occurs generally between 75 and 79 deg corrected geomagnetic latitude and from 0600 to 1800 corrected geomagnetic time in all 15 cross sections. Alouette 1 topside electron-density data, which show the location of the polar F-layer plasma ring and the polar F-layer cavity, are compared with the bottomside ionograms from the aircraft. The data clearly show that the bottomside F-layer irregularity zone and the topside plasma ring are the same feature and that the polar F-layer cavity is a feature common to both measurements. Good spatial correlation exists between the location of the F-layer irregularity zone and the plasma ring and the location of the zone of soft-electron precipitation; thus, soft-electron precipitation is suggested by Pike of AFCRL as the cause of the F-layer irregularity zone.

Several circum-oval flights proved that the auroral oval is a single organic structure rather than consisting of two or more independent features. Besides the discrete and visible aurora, the subvisual auroral emissions were mapped and correlated with soundings and satellite data. An extensive E-layer ("night-E") was found as a universal feature, located in a band about 5 deg wide and attached to the auroral oval on its equatorward side. The layer height across this band from north to south generally drops from about 140 to 120 km, indicating hardening of the energy of the precipitating particles toward the south.

2.3.2 SATELLITE EXPERIMENT RESULTS – IONOSPHERE

2.3.2.1 Spatial and Temporal Variations of the Thermal Plasma

The spatial and temporal variations of the thermal plasma between L = 2 and L = 4 over the altitude range of 3000 to 5700 km have been studied by Sagalyn, et al, of AFCRL, using data obtained from two spherical electrostatic analyzers flown on the polar orbiting satellite OV3-1. During magnetically quiet periods the ionization density is characteristically found to decrease monotonically with increasing L. Between L = 2 and L = 3 a dependence of the average electron density on longitude is found, with the maximum between April and August occurring at 150 deg E and the minimum at 300 deg E. At L < 4, major charge density irregularities are found on 30 percent of the orbits at times of quiet to moderate magnetic activity, sometimes consisting of over an order of magnitude changes in density in less than 0.1L. Comparison of density profiles obtained on the same day at different longitudes shows the irregularities to be of limited longitudinal extent. It is suggested that the depletions result from inward shifts of sectors of the plasma-pause to lower L-shells by E x B drifts. Large-amplitude, small-scale irregularities extending over tens of kilometers are often superimposed on the major density gradients and appear to be the result of instabilities produced by these inward plasma drifts.

2.3.2.2 Thermal Positive Ions in the Outer Ionosphere and Magnetosphere

Sagalyn's group at AFCRL studied the thermal positive ion densities measured with a spherical electrostatic analyzer aboard the OGO-1 and OGO-3 satellites. A delay of 3 to 9 hr is found in the movement of the plasmapause following an increase in the level of magnetic activity on the nightside. Results in the afternoon sector show the plasmapause location correlates best with the magnetic activity that existed previously when the sampled plasma was in the formative night-side region, rather than with the magnetic activity immediately preceding the plasmapause measurement. The density gradient at the plasmapause varies between 3×10^{-2} and 6.0 ions/cm^3/km. The magnitude of the density gradient is inversely related to the plasmapause L-position and is consistently about an order of magnitude higher for the afternoon sector orbits than for the nightside orbits.

2.3.2.3 Observations of Non-Thermal Electrons at High Latitudes

The Injun 5 satellite launched in August 1968 into an orbit between 666 km and 2526 km at an inclination of 80.7 deg carried two plasma probes to measure the flux, density, energy distribution, and temperature of electrons and positive ions with energies between 0 and 2 keV. With this instrumentation, the occurrence of non-thermal energy electrons at high latitudes was studied by Sagalyn's group, using satellite data transmitted in the high-rate mode; the density measurements had a spatial resolution of about 150 m. In the range of invariant latitudes between 60 and 80 deg, small-scale irregularities in the thermal plasma density are often seen; however, the most dramatic features are the large fluxes of electrons with energies in the 1 to 10 eV range that are observed simultaneously in the same region and extend over a hundred kilometers or more. These are observed over the full height range of the satellite orbit and are most likely to be seen in the vicinity of 71 deg invariant latitude. Other instrumentation on the satellite measured electrons in the energy range of from 50 eV to 2 keV; strong fluxes in this energy range are seen concurrently with the lower energy electrons, which indicates a possible observation of the low-energy portion of the electron particle precipitation. In addition, the density of thermal energy electrons falls markedly during the "large flux" events, suggesting that local acceleration is taking place and depleting the ambient thermal plasma. These represent the first simultaneous investigations of thermal and low-energy non-thermal particles in the precipitation zone. The results observed during impulsive precipitation events provide evidence for new mechanisms for thermal particle production and removal in the auroral zone.

2.3.3 IONOSPHERIC SOUNDING ROCKET EXPERIMENTS

2.3.3.1 COSPAR Symposium – PCA 69

The COSPAR-sponsored "Symposium on the November 1969 Solar Particle Event" was held at Boston College on 16, 17, and 18 June 1971. The purpose of the symposium was to present measurements and observations made during the November 1969 solar particle event and to review and discuss present knowledge of solar particle events and their effects on the polar ionosphere. The November 1969 event was of particular significance because of the comprehensive rocket and ground measurement program, called PCA-69, conducted ring the event and the extensive satellite and ground experimental coverage available. Of the 49 papers presented at the symposium, 39 were concerned with the November 1969 event, including 20 based on rocket results, 10 on ground and aircraft observations, and 9 on satellite results. The symposium program was divided into five subject areas with an invited speaker for each. The categories included: the solar proton flare of 2 November 1969; energetic particles and magnetospheric effects; ionospheric effects; aeronomy effects; and the disturbed D-region. Over 120 scientists were in attendance over the 3-day period.

From the symposium presentations it was clear that the main objectives of the PCA-69 program – to make coordinated and comprehensive measurements to study the chemistry of the disturbed D-region – were achieved. In particular the night and day measurements were especially complete, including positive and negative ion composition, electron and ion densities, neutral temperatures and densities, proton and electron flux spectra, optical emissions, and profiles of minor constituents. Not as complete but still significant were the measurements made during the sunrise and sunset transitions. The ground measurements, especially partial reflection, VLF, and riometer results, showed how important coordinated ground experiments are to a rocket program for the investigation of a discreet event, and how valuable they are for studying the time history and the morphology of PCA events. The satellite observations of electron and proton fluxes presented were exceptionally well correlated and comprehensive, indicative of the sophistication and advanced state-of-the-art of satellite instrumentation for energetic particle measurements.

Although the concentration at the symposium was on the presentation of experimental results, preliminary interpretations for solutions to disturbed D-region problems were especially revealing in several presentations. The nighttime results showed that simplified ion chemistry was sufficient to derive a disturbed D-region model for PCA conditions describing positive ion, negative ion, and electron density distributions. The lack of measured cluster ions above 73 km in the day and 77 km at night, resulting in a greatly simplified ion composition during the event, led to revisions in the ion chemistry for disturbed D-regions that subsequently were verified by laboratory studies. Utilizing these in the computer codes and comparing them with rocket daytime measurements showed that the positive ion chemistry for PCA conditions is sufficiently understood, but the negative ion chemistry is not, at present. From the presentations at the sumposium, it now appears possible to derive a time-dependent model of the disturbed D-region for PCA conditions.

2.3.3.2 Small Rocket Ionospheric Experiments

On 6 April 1971, Grieder of AFCRL launched two rockets (A70-4P and -2E) during a PCA event at maximum solar zenith angle (70 deg) for proton flux, electron density, and ion density measurements. A third payload (A70-3E) was launched at minimum solar zenith angle (93 deg) for electron and ion density measurements. Good data were obtained from all flights as well as from a fourth rocket (A70-1E) launched for background measurements. Ground-based observations from the Thule Geopole Station and particle flux measurements from satellites will be utilized in the analysis and interpretation of the data. Two additional rockets (A71-7E and -8E) were successfully launched in the fall of 1971 in support of VLF sounder studies conducted at Thule by the U.S. Navy. Electron and ion densitv measurements were made during quiet daytime and nighttime conditions.

2.3.3.3 Very Low Frequency Propagation Experiments

The penetration of the ionosphere by very low frequency (VLF) radio waves is being studied by Lewis and his colleagues at AFCRL. The latest in a series of experiments to investigate the magnetic latitude dependence of ionospheric transmissivity in the up-going direction was a Black Brant IVA (A16.010-4) launched from Churchill on 31 May 1971, in which Harvey and Harrison monitored the amplitudes and phases of radio waves from six distant ground-based VLF transmitters. The nose cone of the rocket had a fiberglas section containing an electrostatically shielded loop antenna oriented to sense the component of the magnetic field normal to the rocket axis. For control purposes, observations were made simultaneously on the ground at the launch site. A preliminary analysis of the data showed that all six stations were received from the ground to the 500 km apogee. Previously, two Exos rockets (AD13.812 and .815) launched from Eglin AFB in 1965 and two Black Brant IVA rockets (A16.010-1 and -2) launched in 1969 from Natal on the magnetic equator provided signal amplitudes, wave polarizations, doppler shifts, and group velocities as functions of altitude. The results at the magnetic equator differed markedly from those at Eglin: above about 40 km the VLF signals almost completely disappeared at the equator, while at Eglin three distant VLF stations were received continuously all along the trajectory.

Lewis used the data to develop a model for the behavior of the penetrating waves. It is postulated that: (1) the earth-ionosphere waveguide is essentially uniform over quite large distances, (2) the propagating fields uniformly penetrate the ionosphere, and (3) for each mode in the waveguide, the amplitude-phase pattern in a plane transverse to the direction of propagation travels at the model velocity. Knowing the propagation constants at various heights in the ionosphere, the nature of the equiphase surfaces can be deduced from Snell's Law. From the model it is found that between 160 and 500 km the waves propagated in the whistler mode are circularly polarized and travel almost vertically upward, but at a greatly reduced velocity due to the large index of refraction. The model was at least partially validated when the electron density profile at Eglin, calculated from observed values of rocket spin frequency, doppler shift, and wave frequency, was found to be within a few percent of the profile obtained from conventional ground-based HF ionosounders.

2.3.3.4 Daytime Rocket and Thomson Scatter Studies of the Lower Ionosphere

Sagalyn's group at AFCRL completed a comparison of rocket and ground-based radar Thomson scatter (incoherent scatter) measurements of electron densities and temperatures obtained at the same time and location. Two-electrode spherical electrostatic analyzers were used in the rocket experiments. Good agreement is found between the results obtained on two daytime rocket flights and the radar measurements over the altitude range of comparison, 100 to 180 km. The rocket electron-temperature measurements are consistently 10 to 15 percent higher than the radar data. The electron densities agree within 25 percent, which is within the experimental error of the two techniques. Comparison of measured electron temperatures with values calculated from the solution of the heat conduction equation by using methods developed by Dalgarno, et al, shows good agreement below 160 km. Between 200 and 350 km the measured temperatures are 200 to 300 deg higher than predicted. Electron cooling rates were calculated from the experimental results for the relevant cooling mechanisms and were compared with the theoretical heat input to the electron gas. The results imply that the differences between theoretical and experimental temperatures above 200 km are primarily due to an underestimation of the heat input by a factor of 3 to 5.

2.3.4 SATELLITE RELATED IONOSPHERIC STUDIES

2.3.4.1 Propagation Studies Using Satellite Beacons

AFCRL continued its use of both synchronous and low altitude satellites to study the ionosphere. Two approaches, one using the scintillation technique and the second studying total electron content by means of both Faraday rotation and differential doppler, were expanded last year. In addition to monitoring two satellites at 136 and 412 MHz at the Sagamore Hill Radio Observatory, new measurements of both measured parameters were continued at Thule and Narssarssuaq; these measurements have now been reduced with the output in the scintillation studies forming a picture of the irregularity region from below 50 deg invariant latitude to the magnetic pole. The first total electron content measurements using synchronous satellite signals have now been made from latitudes in the polar cap.

2.3.4.2 Ionospheric Scintillation Studies

Using scintillation data from Thule and Narssarssuaq, Aarons, Mullen, and Whitney of AFCRL and Steenstrup of the Danish Meteorological Institute analyzed seasonal, diurnal, and magnetic dependence at 64 deg invariant latitude. Their results indicate the existence of a clear seasonal pattern at the sub-ionospheric latitude. They show some agreement with the curves of Penndorf. From signal strength records of VHF beacons of synchronous satellites, many thousands of hours of data on amplitude scintillations were scaled in terms of scintillation index. These index values have now been converted into cumulative amplitude probability distribution functions by a modelling technique. The amplitude distribution functions were shown to closely agree with Nakagami's m-distribution for various depths of scintillation. These long-term distributions can be used to specify fading margins for ionospheric scintillations in satellite communication systems.

AFCRL satellite observations taken from the Panama Canal Zone were concluded. Three years of scintillation observations showed evidence of nocturnal scintillation approaching 20 dB. While Panama (35 deg N dip) falls outside the usual definition of the equatorial region, during the equinox of 1970 the scintillation morphology was very consistent with that caused by the equatorial ionosphere. This supports the hypothesis of the expansion of the equatorial ionosphere during the decline of the sunspot cycle.

2.4 Geodesy

2.4.1 SATELLITE GEODESY

AFCRL successfully tested an editing technique for detecting and automatically removing whole cycle-count errors that contaminated the prototype GEOCEIVER observations. A new mathematical model for generating tropospheric refraction for ultra-precise corrections was developed. Ray tracing studies were performed for both electronic and optical frequencies and thus provided results valid for both GEOCEIVER and LASER. AFCRL performed several simulations concerning precise positioning of aircraft with a network of GEOCEIVERS. The error propagation of the simulations indicates that when a well-designed, highly redundant, tracking configuration of GEOCEIVERS of known location is exercised over a wide sweep of geometry, accuracies on the order of 0.1 to 0.3 m (1σ) can be expected for the recovery of that portion of the trajectory intercepted by the boundary of the tracking configuration.

AFCRL completed a successful participation in the International Satellite Geodesy Experiment (ISAGEX). The AFCRL dual laser system, combining angular and range capabilities, was used to make successful observations of Explorer 29 (GEOS-A) (1965-089A) and Explorer 36 (GEOS-B) (1968-02A). Error residuals from the ranging data are well within 1 m. The ranging laser is a multi-pulse ruby laser, emitting up to 10 individual ranging pulses per stimulation. The system is now being used in the Earth Physics Satellite Observing Campaign (EPSOC) to make geodetic observations of the Explorer 29 and 36 satellites.

AFCRL's Lunar Laser Observatory, Mt. Lemmon, Pima County, Arizona, has a newly installed 60-in. CER-VIT primary mirror. Observations with this instrument at the new Mt. Lemmon site will begin in January 1972. Analyses of lunar laser range measurements will result in the refinement of many parameters of celestial mechanics; moreover, they will lead to significant improvement in geocentric station coordinates.

2.5 Optical Physics

2.5.1 ROCKET-BORNE OPTICAL MEASUREMENTS

2.5.1.1 Vibrational Temperature of Atmospheric Nitrogen

Stair, O'Neill, and Hart of AFCRL, and Pendleton of Utah State University conducted an experiment to measure the vibrational temperature of atmospheric

N_2 using rocket-based, electron-beam-induced luminescence as a remote diagnostic technique. The vibrational population of molecular nitrogen in the 80 to 175 km altitude range is inferred from the brightness of specific molecular transitions of the N_2^+ first negative band system excited by energetic (2, 5keV) electron impact. Interference filter photometers measured populations of the vibrational levels of the N_2^+ B $^2\Sigma$ state by observing the radiant intensity of the (0-1), (1-2), (2-4), and (3-5) N_2^+ first negative transitions. The results of the initial payload (A03.006-1) launched from Fort Churchill on 13 March 1970 were finalized. Four interference filter photometers measured populations of the first three vibrational levels of the N_2^+ B $^2\Sigma$ state by observing the radiant intensity of the (0-1), (0-2), (1-2), and (2-4) N_2^+ first negative transitions. Ground state nitrogen vibrational populations were derived from N_2^+ first negative vibrational spectra assuming relative electron excitation cross sections proportional to Frank-Condon factors. Anomalies in this interpretation are apparent. Within the experimental uncertainty, determined by the precision of the rocket instrumentation and the nature of the experimental technique, little, if any, significant vibrational heating above kinetic temperature was measured. An upper limit of N_2 vibrational temperature was determined in the altitude range 80 to 175 km (1200°K at 175 km, 1000°K at 150 km, and less than 800°K at altitudes lower than 125 km). Absolute molecular density of N_2 in the 106 to 175 km range was measured with values significantly less than the CIRA 1965 mean model atmosphere. A second payload (A03.910-1) was launched on 16 October 1971 from White Sands. The number of photometers was increased to six for measuring N_2 vibrational temperature by observing N_2^+ first negative (0-1), (1-2), (2-4), and (3-5) transitions, measuring N_2 kinetic temperature by means of N_2^+ first negative (0-1) rotational structure and O_2 molecular density by O_2^+ first negative emission at 5590Å. Electron beam current was increased from 6 to 25 mA on the second payload, and an in-flight calibration lamp was included in an effort to provide more accurate vibrational temperatures. Preliminary indication is that all instrumentation functioned successfully and good data were obtained.

2.5.1.2 Infrared Sources in the Celestial Sphere

Walker's group at AFCRL commenced a program to measure and map infrared sources in the celestial sphere in 1971. Emphasis was placed upon the 5-, 11-, and 19-μ wavelength regions. Three instrumented rockets were launched from White Sands successfully (A04.004-2, .004-4, and .004-5 on 3 April, 29 June, and 29 October, respectively). Preliminary analysis of the data from the first flight (A04.004-2) indicated a myriad of sources in all three wavelengths. Data from the second and third flights are being reduced and analyzed.

2.5.1.3 Atmospheric Scattering

Fenn and Toolin of AFCRL conducted a rocket experiment (A04.012-1) from White Sands on 3 November to measure atmospheric optical scattering at small angles from the solar disc. Bolle of the University of Munich flew infrared and ultraviolet radiometers on the same vehicle to measure atmospheric trace gases. Sun pointing was not achieved because the payload did not separate from the sustainer; however, data appears to have been obtained from a side-looking OH experiment.

2.5.2 BALLOON-BORNE OPTICAL MEASUREMENTS

2.5.2.1 Radiometric Measurement of Martian Irradiance

Logan of AFCRL successfully measured Martian irradiance using a balloon-borne, 70-cm-aperture telescope system at a float altitude of 34.4 km; it was launched from Holloman on 4 April. The experiment used a liquid-helium cooled, copper-doped germanium detector with a wavelength response restricted to the band between 10. 5 and 12.5μ by a cooled filter inside the detector. The reflectivities of uncooled reflecting surfaces, such as the telescope mirrors, beam splitter, and chopper, were measured prior to flight, and the temperatures of these elements were monitored during the flight. The image profile of Mars was mapped by scanning the telescope in a raster pattern. Seven such raster scans were made with calibration routines interspersed. The average brightness temperature of Mars was found to be 254^{o}K with a 1σ error of 4^{o}K.

2.5.2.2 Aerosol Measurements

Fenn of AFCRL conducted the first balloon flight of a newly developed aerosol counter on 28 October 1970 from Holloman, N.M. (Flight H70-66). The particle counter operates on the principle of a ratio and intensity measurement of two optical signals derived from the photoelectric detection of light scattered from a HeNe laser (0.6328 μm) by individual aerosol particles into forward scattering angles of 10 deg $\pm$ 5 deg. and 30 deg $\pm$ 5 deg, respectively. The size of particles between 0.2 and 1 μm diameter is discriminated with an accuracy of approximately $\pm$10 percent. The 10 deg/30 deg scattering ratio over this size range at the HeNe laser wavelength depends very little on the particle refractive index. The 500 lb payload was flown on a 2 million cu ft balloon with a 500 ft let-down reel separation; launch was at 1402:30 UT, peak altitude was 23.8 km. The measured total particle numbers between 0.2 and 1.0 μm diameter decreased from about 2 to 3 particles/cm^3 at 7 km altitude to about 0.8 per cm^3 over the altitude range from 12 to 18 km. The concentrations increase by about a factor of 2 between 18 and 22 km and then decrease again above 22 km. The size distributions vary between $N \sim r^{-3}$ to $N \sim r^{-5}$, with the steeper size distributions generally associated with the ascent data and the flatter distributions with descent data. The possible causes for this difference are presently being studied.

Data from an AFCRL balloon flight (H70-73), launched from Holloman in November 1970, provided new information on the angular volume scattering function of the atmosphere, from ground to better than 26 km. In addition, polarization and forward-to-backscatter ratios provided corroborative evidence of aerosol scattering in both the troposphere and stratosphere. At least four distinct dust layers in the stratosphere (between 17 and 26 km) were identifiable, with an average thickness of approximately 0.3 km. The results showed that the polarization is indeed a sensitive indicator of aerosol scattering and varies inversely with turbidity. This parameter in conjunction with the absolute measurements of the volume scattering function provides the nephelometer with a self-consistent capability. The experimental payload consisted of a large modified polar nephelometer with a xenon light source, operated in a modulated cw mode, and five observation photometers, which view the projected beam at angles of 22, 45, 90, 135, and 157 deg. The volume defined by the intersection of the source beam and detector field-of-view contains the air molecules and aerosols, the scattering properties of which are measured. In particular, the intensity and polarization of the scattered light are detected, at visible and near infrared wavelengths, as the balloon ascends and descends.

Appendix A

AFCRL Rocket and Satellite Experiments—1971

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Table A1. AFCRL Satellites/Experiments — 1971

Scientific Designation	Popular Name	Lifetime (Launch/ Decay)	Experiments	Initial Orbital Elements			
				Apogee (km)	Perigee (km)	Period (min)	Inclination (deg)
1971-067B	OV1-21	Aug 71/ Oct 71*	Neutral Composition (Velocity Mass Spectrometer)	914	791	101.9	87.6
1971-067C	Cannonball II	Aug 71/	Low Altitude Density (Accelerometer Technique)	1957	134	106	91.9
1971-067D	Musketball	Aug 71/ Sept 71	Low Altitude Density (Satellite Drag Technique)	865	138	96	87.61

*Battery lifetime

Table A2. AFCRL Sounding Rocket Launchings – 1971

Date (UT)	Time (UT)	Rocket No. or Type	Launch Site	Experiment Title	Alt (Km)	Principal Scientist
8 Jan	2141	A07.016-3	WSMR	Density Measurements (7 in. Falling Sphere)	280	A. C. Faire
8 Jan	2231	A07.015-2	WSMR	Density Measurements (7 in. Falling Sphere)	278	A. C. Faire
12 Mar	0513	A07.015-3	WSMR	Density Measurements (7 in. Falling Sphere)	282	A. C. Faire
12 Mar	0655	A07.913-3	WSMR	Density Measurements (7 in. Falling Sphere)	262	A. C. Faire
16 Mar	1900	A04.002-2	WSMR	Solar Extreme Ultraviolet	274	H. Hinteregger
20 Mar	0542	A08.019-1	CRR	Magnetic Fields and Charged Particles	339	R. Vancour
20 Mar	0544	A07.019-2	CRR	Magnetic Fields and Charged Particles	165	R. Vancour
22 Mar	1640	A70-1E	Thule	Electron and Ion Density	107	W. F. Grieder
24 Mar	0526	A18.006-3	CRR	IR Aurora and Airglow Measurements	369	A. T. Stair and D. Kimball
3 Apr	0950	A04.004-2	WSMR	IR Stellar Sources (Project Hi-Star)	160	R. Walker
6 Apr	1719	A70-4P	Thule	Proton Flux - PCA	85	W. F. Grieder
6 Apr	1753	A70-2E	Thule	Electron and Ion Density	108	W. F. Grieder
7 Apr	0430	A70-3E	Thule	Electron and Ion Density	118	W. F. Grieder
6 May	0116	A07.902-7	ADTC	Composition (Mass Spectrometer)	121	R. Narcisi
8 May	1615	A07.902-8	ADTC	Positive Ion Composition (Mass Spectrometer)	136	R. Narcisi
18 May	0024	A07.913-5	ADTC	Density Measurements (7 in. Sphere and Optical) (Project "HAVE GENIE")	146	A. C. Faire and L. Weeks

Table A2. AFCRL Sounding Rocket Launchings —1971 (Contd)

Date (UT)	Time (UT)	Rocket No. or Type	Launch Site	Experiment Title	Alt (Km)	Principal Scientist
18 May	0105	A07.917-5	ADTC	Ionospheric Winds (Chemical Release) (Project "HAVE GENIE")	180	N. W. Rosenberg
18 May	0108	A07.918-2	ADTC	AlO Temperatures (Chemical Release) (Project "HAVE GENIE")	151	N. W. Rosenberg
18 May	0206	A07.921-1	ADTC	Density and Chemical Release (7 in. Sphere and TMA) (Project "HAVE GENIE")	151	N. W. Rosenberg and A. C. Faire
18 May	0241	A08.919-2	ADTC	Atomic Oxygen Profile (Chemical Release) (Project "HAVE GENIE")	204	N. W. Rosenberg
18 May	0305	A07.918-4	ADTC	Exploratory Studies (Chemical Release) (Project "HAVE GENIE")	159	N. W. Rosenberg
18 May	1009	A07.917-6	ADTC	Ionospheric Winds (Chemical Release) (Project "HAVE GENIE")	148	N. W. Rosenberg
19 May	0114	A07.918-3	ADTC	AlO Temperature (Chemical Release)	137	N. W. Rosenberg
21 May	0115	A07.917-4	ADTC	Ionospheric Winds (Chemical Release)	165	N. W. Rosenberg
31 May	1935	A16.010-4	CRR	VLF Ionospheric Absorption	733	R. B. Harvey
29 June	0710	A04.004-4	WSMR	IR Stellar Sources (Project Hi-Star)	160	R. Walker
27 Sept	0830	A07.914-1	WSMR	Density Measurements (Bremsstrahlung Technique)	169	H. Cohen
5 Oct	1830	A08.103-2	WOPS	Density Measurements (O_2 and O_3) (Twilight Neutral Studies Program)	277	L. Weeks
5 Oct	2232	A07.913-6A	WOPS	Density Measurements (O_2 and O_3) (Twilight Neutral Studies Program)	187	L. Weeks
5 Oct	2233	A07.101-5	WOPS	Neutral Composition (Mass Spectrometer) (Twilight Neutral Studies Program)	116	C. R. Philbrick
5 Oct	2242	A07.102-4	WOPS	Density Measurements (7 in. Sphere) (Twilight Neutral Studies Program)	232	A. C. Faire

Table A2. AFCRL Sounding Rocket Launchings — 1971 (Contd)

Date (UT)	Time (UT)	Rocket No. or Type	Launch Site	Experiment Title	Alt (Km)	Principal Scientist
5 Oct	2303	A07.913-6	WOPS	Density Measurements (7 in. Sphere) (Twilight Neutral Studies Program)	51	A. C. Faire
6 Oct	0045	A07.101-6	WOPS	Neutral Composition (Mass Spectrometer) (Twilight Neutral Studies Program)	120	C. R. Philbrick
6 Oct	1000	A07.902-6	WOPS	Positive Ions (Mass Spectrometer) (Sunrise Ion Composition Studies Program)	120	R. Narcisi
6 Oct	1011	A07.101-3	WOPS	Negative Ions (Mass Spectrometer) (Sunrise Ion Composition Studies Program)	115	R. Narcisi
6 Oct	1044	A07.101-4	WOPS	Negative Ions (Mass Spectrometer) (Sunrise Ion Composition Studies Program)	116	R. Narcisi
6 Oct	1105	A07.101-2	WOPS	Positive Ions (Mass Spectrometer) (Sunrise Ion Composition Studies Program)	115	R. Narcisi
16 Oct	0231	A03.910-1	WSMR	N_2 Vibrational Temperature	216	A. T. Stair and R. O'Neill
23 Oct	1630	A71-7E	Thule	D-Region Ionization - Daytime	106	W. F. Grieder
29 Oct	1109	A04.004-5	WSMR	IR Stellar Sources (Project Hi-Star)	157	R. Walker
3 Nov	1230	A04.012-1	WSMR	Atmospheric Extinction	251	R. W. Fenn
4 Nov	0030	A71-8E	Thule	D-Region Ionization - Nighttime	107	W. F. Grieder
9 Nov	1900	A03.002-3	WSMR	Solar Extreme Ultraviolet	219	J. E. Higgins
9 Nov	1900	A03.002-4	WSMR	Solar Extreme Ultraviolet	215	J. E. Hanson
16 Nov	2318	A07.106-5	ADTC	Chemical Release Studies	166	N. W. Rosenberg

Appendix B

AFCRL Rocket and Satellite Experiments Planned for 1972

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Table B1. AFCRL Satellite Experiments Planned for 1972

Spacecraft	Scientist	Experiment Title	Launch Site
S71-5	J. McIsaac	Atmospheric Density (Ionization Gauge)	WTR
P72-1	J. Kelley	Low Altitude Particles	WTR

Table B2. AFCRL Sounding Rocket Experiments Planned for 1972

Experimenter	Experiment	Launch Site(s)
Cohen, H.	Atmospheric Density (Bremsstrahlung)	WS
Faire, A. C.	Atmospheric Density (Falling Sphere)	Eglin/WI/WS
Golomb, D.	Atomic Oxygen Variation	Eglin
Hinteregger, H.	Solar Extreme Ultraviolet (Spectrometric Technique)	Eglin/WS
Narcisi, R. S.	Sudden Ionospheric Disturbances	Eglin
Narcisi, R. S.	Atmospheric Composition (Positives, Negatives and Neutrals)	Eglin
Narcisi, R. S.	D-Region Cluster Ions	Eglin
Philbrick, R.	Atmospheric Composition	FC
Rosenberg, N. W.	Ionospheric Wind Variations and Studies (Chemical Releases)	Eglin
Rosenberg, N. W.	Upper Atmosphere Studies (Chemical Releases)	Eglin
Rotman, W.	Reentry Microwave Physics	WI
Sagalyn, R. C.	Electric Fields and Plasmas	FC
Sherman, C.	Vehicle Potential Stabilization	Eglin
Shuman, B. M.	Detection of Field-Aligned Currents	FC
Stair, A. T.	Infrared Airglow	FC
Ulwick, J.	Sudden Ionospheric Disturbances	Poker Flat/FC
Vancour, R.	Disturbed Magnetic Fields	FC
Walker, R. G.	Infrared Stellar Sources	WS
Walker, R. G.	Infrared Earth Limb	WS
Weeks, L	Atmospheric Density (Optical Techniques)	WS/Eglin